SEMI-ANNUAL TECHNICAL SUMMARY OF RESEARCH OF AEROPHYSICS INSTITUTE FOR STRATEGIC TECHNOLOGY

for the period ending 28 February 1971

Sponsored by

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13 ABSTRACT

This report contains a description of the technical problem areas and accomplishments achieved during the reporting period. In addition, a complete list of publications, presentations, lectures, etc. is included and the personnel associated with this program are listed. The research projects are in the general subject areas of fluid and plasma dynamics. The work described was carried out under an ARPA contract, Order No. 1442, Amendment 2.

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PIBAL
Report 71-A

for
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Submitted by: Martin H. Bloom
Principal Investigator
Director of Gas Dynamics
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ABSTRACT

This report contains a description of the technical problem areas and accomplishments achieved during the reporting period. In addition, a complete list of publications, presentations, lectures, etc. is included and the personnel associated with this program are listed. The research projects are in the general subject areas of fluid and plasma dynamics. The work described was carried out under an ARPA contract, Order No. 1442, Amendment 2.

I. INTRODUCTION

The Polytechnic Institute of Brooklyn is conducting an interdisciplinary program involving both theoretical and experimental studies in the areas of aerodynamics, plasma dynamics, and turbulence. In particular, those aspects are dealt with which are directly applicable to the immediate and long range interests of the ARPA Strategic Technology Office. Laboratory simulations, experimental devices and comparison of results with observed flight behavior are under consideration. Generation of new ideas and the review and evaluation of research performed by others in the professional community is also a significant part of the research effort.

In addition to the research studies briefly summarized in the following section, the investigators are engaged in ARPA committees and discussions and normally participate in the various workshops and meetings pertinent to the overall program.

II. RESEARCH PROJECTS

In this section, the various technical aspects of the individual research projects are discussed. In addition to a description of the task, the investigators, including faculty and students, and the current effort and major accomplishments to date are described. The relevance to national defense is also indicated in each of the project summaries. The various research areas are listed here for reference:

A. Flow Diagnostic Development

B. Ion Collection by Langmuir Probes

C. Wake Transition Measurements

D. Turbulent Jets and Wakes

E. "Slingshot" - An Aerodynamic Test Facility

F. Fluctuations in Beam-Plasma Systems

G. Weak Turbulence in Plasmas

H. Plasma Cloud Diffusion

A. Flow Diagnostic Development

Investigator: Professor Samuel Lederman

Technical Program and Accomplishments:

The development and understanding of the behavior of various flow diagnostic devices was the main concern of this study. Particular emphasis was placed upon electrostatic probes of cylindrical and flush mounted variety and Raman scattering of laser radiation.

As a continuation of the previous studies of the cylindrical electrostatic probe in a free molecular regime[1], a study was undertaken to determine the behavior of these probes in the transitional and continuum regime. The results of this study are presented in Ref. 2. The behavior of flush mounted electrostatic probes in a continuum and a rarefied regime at supersonic and hypersonic flow velocities was also investigated. The results of this work are presented in Refs. 3 and 4. At the same time, an investigation of the end effect on the current collection of cylindrical probes in a rarefied slightly ionized flow was undertaken. A report on the results of this work is now in preparation.

The work on the development of the Raman scattered radiation measuring technique for density and specie concentration and temperature

determination was continued. Some results of this work are presented in Ref. 5. A further report on some aspects of this work is in preparation and should be published soon.

References:

1. Lederman, S., Bloom, M.H. and Widhopf, G.: Experiments on Cylindrical Electrostatic Probes in Slightly Ionized Hypersonic Flow. AIAA J., 6, 11, pp. 2133-2139, November 1968. Paper presented at the AIAA 6th Aerospace Sciences Meeting, New York, Jan. 22-24, 1968.

2. Lederman,S., Bloom, M.H. and Avidor, J.: The Electrostatic Probe: Some Applications to Hypersonic Flow Diagnostics. Israel J. of Tech., 8, 1-2, pp. 73-85, 1970. Paper presented at the Twelfth Israel Annual Conference on Aviation and Astronautics, Tel Aviv, Israel, March 4-5, 1970.

3. Lederman, S. and Avidor, J.: The Application of Flush Mounted Electrostatic Probes to Flow Diagnostics. Israel J. of Tech., 9, 1-2, 1971. Paper to be presented at the Thirteenth Israel Annual Conference on Aviation and Astronautics, Tel Aviv, Israel, March 3-4, 1971.

4. Lederman, S. and Bushman, R.W.: Flush Electrostatic Probe in a Continuum Regime. Polytechnic Institute of Brooklyn, PIBAL Report No. 70-54, December 1970.

5. Widhopf, G.F. and Lederman, S.: Specie Concentration Measurements Utilizing Raman Scattering of a Laser Beam. Polytechnic Institute of Brooklyn. PIBAL Report No. 69-46, AD 701343, November 1969. Also, AIAA J., 9, 2, pp. 309-316, February 1971.

B. Ion Collection by Langmuir Probes

Investigators: Professor E. Levi, Dr. C.H. Shih

Technical Program and Achievements:

The objective is to determine the transient as well as the steady state behavior of negatively biased Langmuir probes with particular reference to the transitional regime.

A simple steady-state theory which accounts separately for the effects of collisions between charged particles and collisions with neutrals was developed. When the theory was applied to recent experimental data taken with spherical and cylindrical probes, the electron densities calculated from the probe measurements by using the present theory agreed within 10 percent with those inferred from existing numerical solutions the empirical formula of Lederman, Bloom and Widhopf, and microwave cavity data.

The same theory can be applied to determine the cross-sections for ion-ion and ion-neutral collisions and deduce related quantities, such as the ion temperature, the chemical composition of the plasma and the density of the background gas. Good agreement was obtained between theory and experimental data taken in quite distinct physical situations, by using a hypersonic shock-tunnel and a laser discharge. This method could be applied to the determination of ion-neutral collision cross-sections in the transition region between D and E - layers of the ionosphere.

Extending the investigation to transient behavior, analytical expressions were derived for the response of planar and cylindrical ion sheaths to large amplitude and sudden changes in the biasing potentials. It was found that the speed of response depends on the sign of the change,

this asymmetry being particularly pronounced with planar probes. Equivalent circuits describing the dynamic response of probes in the collisional, as well as the collisionless regimes, were derived. These circuits show that the time constants characterizing the probe response can exceed $1/\omega_{p_i}$ by one order of magnitude. However, at frequencies below $10^{-2}\omega_{p_i}$, a frequency range of great interest for the study of turbulence, the dynamic performance of the probes can be approximated by a succession of quasi-steady states. Expressions were derived which relate the mean and the variance of the probe current to the auto and cross correlations of fluctuations in density, temperature, and potential. Particular attention was given to the two cases in which (a) the density fluctuation is overriding and attains large amplitude, a likely occurrence with slightly ionized gases; and (b) the level of fluctuations is low, but more than one type is simultaneously present. All theoretical results were found to be consistent with experimental evidence reported in the published literature.

These studies close the remaining gaps in the application of negatively biased Langmuir probes by extending their use to the diagnostics of the transitional regime, transient phenomena and turbulence.

Detailed Significance

The development of diagnostic tools in general serves a twofold purpose: (1) it improves the accuracy of data acquisitions; (2) it enhances the understanding of those physical phenomena which are involved in the probe operation. With respect to the first aim, the technologies of nuclear weaponry, vehicle reentry, and [illegible] radar and [illegible] systems stand to gain from more reliable measurements and [illegible].

identification. With respect to the second aim, this work has contributed to a qualitative and quantitative evaluation of plasma shielding by means of space charge sheaths, the most typical phenomenon of the fourth state of matter.

References:

1. Self, S.A. and Shih, C.H.: Theory and Measurements for Ion Collection by a Spherical Probe in a Collisional Plasma. Phys. Fluids, 11, p. 1532, 1968.
2. Lederman, S., Bloom, M.H. and Widhopf, G.F.: Experiments on Cylindrical Electrostatic Probes in Slightly Ionized Hypersonic Flows. AIAA J., 6, p. 2133, 1968.
3. Shih, C.H. and Levi, E.: The Effect of Collisions on Cold Ion Collection by Means of Langmuir Probes. Presented at the AIAA Third Fluid and Plasma Dynamics Conference, Los Angeles, California, June 28-July 1, 1970, AIAA Paper No. 70-757.
4. Shih, C.H. and Levi, E.: The Effect of Collisions on Cold Ion Collection by Means of Langmuir Probes. To be published in the AIAA J.
5. Shih, C.H. and Levi, E.: Determination of the Collision Parameters by Means of Langmuir Probes. Submitted to the AIAA J. in September 1970.
6. Shih, C.H. and Levi, E.: Transient Performance of Negatively Biased Langmuir Probes. Submitted to the AIAA J. in December 1970.
7. Shih, C.H. and Levi, E.: Ion Collection by Means of Langmuir Probes. Polytechnic Institute of Brooklyn, Report PIBEP-71-084, March 1971.

C. Wake Transition Measurements

Investigators: Professor R.J. Cresci
Mr. P. Rosner

Technical Program and Accomplishments:

In recent years, much time and effort has been expended in the investigation of the wake of reentry bodies. The justification for this interest lies in the fact that the wake represents a source of radar observables. Although much of this study has been concerned with the laminar wake, more recently the transitional and turbulent wake characteristics are of interest. The object of this study is to determine large scale changes in wake observables as the surface boundary layer goes through a transitional and turbulent state. This work was conducted in the Mach 8 tunnel at PIB in which a large variation of Reynolds number can be achieved. For the 10° half angle, sharp cone, model previous studies have shown that the boundary layer can be varied from completely laminar to fully turbulent in the vicinity of the cone shoulder. Mean flow properties such as velocity, pressure, and density, were obtained between the base and 10 diameters downstream of the base under variable Reynolds number conditions. In contrast to free flight observables, no significant changes were observed in the mean variables. In order to determine, therefore, the extent and nature of the wake transition mechanism, hot wire surveys have recently been obtained. These surveys were conducted at 3.3 base diameters downstream of the model. In this region, empirical correlations of ballistic range data have indicated that transition should be initiated at the test Reynolds numbers.

The results of this study are quite preliminary in that it was not

possible either to obtain spectra, distributions or to separate the turbulence modes (i.e., vorticity, sound, entropy) from the RMS data measured. The high speed recording and analyzing equipment required for this was not available at PIB. In addition, the variation of the RMS fluctuations (on centerline in the near wake) was continuously increasing with test Reynolds number; it was, therefore, not possible to determine a particular location of wake transition without more extensive data analysis and equipment.

Defense Significance:

Detection of high speed reentry vehicles is directly related to the radar return information available. It is, therefore, extremely important to have an understanding and capability of prediction of the wake observables under varying conditions of velocity and altitude. At present there seem to be some conditions that are not clearly understood, between data obtained under free flight conditions and in ground test facilities. A continuation of the present study should help to achieve a better understanding of these anomalies.

References:

1. Rosner, P.: Hot-Wire Turbulence Measurements in the Near Wake of a Slender Cone. M S. Thesis, Polytechnic Institute of Brooklyn, June 1971.

D. Turbulent Jets and Wakes

Investigator: Professor P.M. Gorza

Technical Program and Accomplishments:

A semi-empirical description of hypersonic wedge near wake establishment time has been completed[1]. The model is applicable to high angle entry and ascent vehicles and may be readily extended to conical bodies. As an offshoot of this study an analytic investigation of low Reynolds number unsteady flows in circular cavities has led to an analytic solution for such flows with arbitrary initial wall velocity distributions; this model bears resemblance, in many respects, to the near wake recirculation region flow field[2]. Experiments made at PIBAL several years ago[3] are being utilized in the theoretical study of three-dimensional low speed wakes. This study has not been completed and no unusual results have been thus far achieved.

Chemical reactions in turbulent mixing has been investigated in some detail at PIBAL. A critical review of this topic appears in Ref. 4. Also included in Ref. 4 is an experimental and theoretical investigation of combustion of an unpremixed natural gas-air coaxial turbulent jet. The review portion illustrates the primitive state of affairs extant in the field, both in theory and diagnostic techniques. Since that time we have devoted much effort to that area and have developed significant new results which led to the design of refined instruments. We have developed an improved isokinetic gas sampling probe and associated equipment for concentration measurements in binary mixtures. In addition, an improved calirometric probe for measuring enthalpy flux and temperature has been constructed. The extended "inductive theory of free turbulence" developed

at PIBAL has been further substantiated by our measurements of mass transfer in turbulent jets with the new probe.

The TANDEL (temperature autostabilizing nonlinear dielectric element) had been brought to an operation state at the middle of last year. The principal researcher on this facet of the program has since relocated. He is continuing to improve the capability of the TANDEL and it is planned to have a working unit at PIBAL for testing during the next contract period.

References:

1. Sforza, P.M.: An Approximate Analysis for the Establishment of Hypersonic Near Wakes. Polytechnic Institute of Brooklyn, (Internal Memorandum).
2. Sforza, P.M. and Valentine, R.: Unsteady Flow Within a Circular Cavity. Paper to be presented at the IUTAM Symposium on Unsteady Boundary Layers, Laval University, Quebec, Canada, May 25-29, 1971.
3. Nardella, M.: Experimental Investigation of Three-Dimensional Near Wakes. Polytechnic Institute of Brooklyn, M.S. (Astronautics) Thesis, June 1967.
4. Mons, R.F. and Sforza, P.M.: Chemical Reactions in Compressible Turbulent Mixing Flows. Presented at the AIAA 5th Propulsion Joint Specialist Conference, USAF Academy, Colorado, June 9-13, 1969, AIAA Paper No. 69-537.

E. "Slingshot" - An Aerodynamic Test Facility

Investigators: Professors M.H. Bloom and R.J. Cresci
Mr. D. Landsberg

Technical Program and Accomplishments:

The objective of this study is to develop a pilot model of an advanced design, aerodynamic test facility. The concept consists of accelerating a capsule of test gas in a gun barrel thereby achieving high Mach number flow over a stationary model. Some advantages of this concept over presently available facilities are the achievement of high Reynolds number, and complete simulation of atmospheric properties.

Using an available 2" pipe of approximately 65 feet in length, a 5" I.D. driver section has been constructed as well as a model support window and various instrumentation devices. At present, velocities up to 3800 ft/sec have been achieved and cone models have been tested, including the measurement of surface pressure and surface heat transfer. The optimal driver technique has been studied with the ultimate aim of obtaining high velocity, shock-free flow. The theoretical analysis of the flow inside the capsule has also been developed and is being used to obtain a more effective acceleration history. It has been found theoretically that shock-free flow can be obtained by starting the capsule trajectory with a low acceleration and increasing the acceleration with time. In this manner, velocities on the order of 20,000 fps are realizable in a gun barrel on the order of 200 ft. in length.

Defense Significance:

This device can be used in the ground test of high speed, low altitude, intercept vehicles. The test atmosphere is readily controlled in that one can insert any mixture of gases, vapors, or solid particles

into the capsule. It is anticipated that this device, in addition to its usefulness for high Reynolds number tests, can also be effective in the measurement of surface erosion in traversing an atmosphere laden with either solid particles or water vapor.

References:

1. Bloom, M.H., Cresci, R.J., Moretti, G., and Librizzi, J.: "Slingshot"- An Advanced Aerodynamic Test Facility. Polytechnic Institute of Brooklyn, PIBAL Report No. 69-24, July 1969. Paper presented at the Seventh International Shock Tube Symposium, Toronto, Canada, June 1969.

2. Librizzi, J.: "Slingshot" - Experimental and Analytical Performance. Ph.D. Thesis, Polytechnic Institute of Brooklyn, June 1970.

F. Fluctuations in Beam-Plasma Systems

Investigators: Professors R.G.E. Hutter, H. Farber and E. Levi
Mr. R. Eichler

Technical Program and Accomplishments:

The objective is to investigate fluctuation phenomena (first noise, later turbulence) in plasmas or ionized gases by means of the effects impressed on a beam of electrons which traverse these media. The final goal of this work is to determine the feasibility of using an electron beam as a diagnostic tool for determination of the properties of a noisy and/or turbulent ionized medium. Theoretical studies are being made to derive expressions for the signals impressed on an electron beam passing through an ionized medium of various characteristics; these studies are paralleled by experimental work which is designed to approximate the theoretical model. A device has been in operation which consists of a

plasma chamber through which an electron beam is passing. Microwave cavities and probes are used to determine the signal on the beam both before it enters, and after it leaves the plasma. It is the intent to first study simple plasmas and to establish meaningful comparison between theory and experiment, before studying more complicated turbulent plasmas.

The current status of the program follows: It was found that the experimental plasma, a low-voltage arc discharge was far from quiescent and a great variety of signals were detected by the electron beam. To demonstrate that the beam detects signals caused by plasma fluctuations, additional fluctuations were introduced by means of a modulating signal. It was clearly shown that the detected signal had the characteristics of these deliberately introduced fluctuations.

The theory applicable to the simple case of a laterally infinite beam-plasma system is complete; only some numerical evaluations remain such that quantitative information can be derived for various ranges of beam and plasma parameters. The theory is presently being extended to apply to more realistic configurations such as finite diameter electron beams and finite plasmas.

Defense Significance:

Studies of the turbulence present in the aftereffects of nuclear explosions, in reentry wakes, in the ionosphere and magnetosphere, in gas dynamic lasers will benefit greatly by efforts which lead to new diagnostic tools for experimental investigations and from efforts which increase the knowledge of the range of applicability of such tools.

G. Weak Turbulence in Plasmas

Investigators: Professors K. Chung and E. Levi
Dr. K.C. Huang and Mr. R. Kristal

Technical Program and Accomplishments:

The lifetime of a plasmas structure is determined by the loss of energy and particles. Weak turbulence has since long been suspected to be a major factor in enhancing this loss. However, a quantitative correlation has, until very recently, eluded both theoretical prediction and experimental detection. The objective of the present study is to establish such a correlation by simultaneous measurement of the levels of the fluctuations and losses under carefully controlled experimental conditions and to explain these findings on the basis of a linear analysis, if applicable, or on the basis of the reciprocal interaction between the background plasma state and the fluctuation field, if feasible.

Considerable success has been attained with the first task in a hollow cathode arc plasma, where the increase in density fluctuation level from 1% to 25% has been positively correlated with an increase in the coefficient of diffusion across the magnetic field of three orders of magnitude. The values of $D_\perp$ detected in the quiescent and weakly turbulent regimes correspond to those expected for classical and Bohm diffusion respectively. Since the short-circulating effects of end plates has been carefully avoided, Simon diffusion is ruled out.

It has been observed that the correlation time of the fluctuations corresponds to the transit time of the ions along the device. This seems to indicate that the unstable modes do not reach saturation and that

linear analysis should be applicable. Unfortunately, the specific parameters of this plasma do not allow the ordering of the length and time scales on which existing analyses are based. The theory is presently being extended to cover realistic situations.

Defense Significance:

Weak plasma turbulence is significant since it controls the generation and time evolution of high altitude plasma structures both natural and man-made. It also leads to enormously high radar cross-sections. A more complete understanding of these phenomena is essential for the design of ABM and radar systems as well as for the evaluation of radar return information.

H. Plasma Cloud Diffusion

Investigators: Professors E. Levi, K.M. Chung, and R.G.E. Hutter

Technical Program and Accomplishments:

This study is concerned with the development of techniques aimed at inhibiting the formation of striations in plasmas.

Striations have been observed not only in plasma clouds, but also in natural auroras and magnetospheric plasmas They are considered to be the nonlinear evolutionary phase of drift instabilities, a type of instability which has been successfully suppressed in laboratory experiments.

Despite the relatively low level of effort, the PIB group has succeeded in producing and controlling field-aligned striations under laboratory conditions, and in affecting both the growth rate and the nonlinear saturation level of drift instabilities by dynamic stabilization techniques. Work is also in progress on the feedback control of such instabilities.

It is proposed to continue the initial theoretical and experimental investigations on the nature of these striations and on the most effective techniques for r-f illumination.

References:

1. Chung, K., J. Appl. Phys. 40, p. 3885 (1969).
2. Chung, K., Bull. Am. Phys. Soc. 14, p. 830 (1969).
3. Levi, E., Project Secede 1969 Summer Study Proceedings, II, p. 3.
4. Levi, E., Project Secede 1970 Summer Study Proceedings, III, p. 205.

III. SUMMARY OF PUBLICATIONS, REPORTS AND PRESENTATIONS

A. Published Articles

G.F. Widhopf and S. Lederman, "Specie Concentration Measurements Utilizing Raman Scattering of a Laser Beam"*, published in the AIAA Journal, Vol. 9, No. 2, pp. 309-316, February 1971.

The feasibility of utilizing Raman scattering as a diagnostic technique to measure individual specie concentrations in typical gas mixtures found in gas-dynamic applications has been investigated and demonstrated. Utilizing this technique, either the local density of a pure gas or the concentration of individual diatomic (or polyatomic) species in a gas mixture can be uniquely determined. The range and limitations of this technique were investigated and evaluated under controlled static conditions. A Q-switched ruby laser, which has a pulse duration of approximately 10 nsec, was used as a radiation source. Quantitative experimental results are given for some typical gases in their pure state, as well as in various mixture proportions.

M.H. Bloom, R.J. Cresci, G. Moretti, and J. Librizzi, "Slingshot - An Advanced Aerodynamic Test Facility"*, published in the Proceedings of the Seventh International Shock Tube Symposium ed. by I.I. Glass, Univ. of Toronto Press, Canada, 1970.

A conceptual view is presented of the SLINGSHOT method of mechanically setting fluids or other materials into motion with respect to models. In the special context of gas-dynamic testing, unpreprocessed

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*Research supported in part under Contract Nonr 839(38).

test gas is made available at high Reynolds numbers and high Mach numbers with fixed models. Performance in regimes now inaccessible with fixed models is theoretically possible; however, practical implementation may require significant effort. Exploratory experiments made with the simplest conceivable apparatus show agreement with estimated model pressures and running times. The basic setup now consists of a gas-gun accelerated capsule containing the test gas, 2" dia. x 12" in length, which has been driven to 3600 fps. An analysis of the internal wave behavior agrees with the experimental observation indicating the absence of shocks within the test gas. Among the main problems are running-time limits, booster simplicity, and disposal of capsule debris. Examination of somewhat higher performance conditions appears warranted.

B. Presentations at Technical Meetings

R. J. Cresci, "Liquid Film Cooling", presented at the Transpiration Cooling Workshop, held at Aerospace Corporation, San Bernardino, Calif., January 5, 1971.

T. Koga, "Distinction Between Classical Kinetic Theory and Quantal Kinetic Theory", presented at the 12th Annual Meeting of the Plasma Physics Division of the American Physical Society, held in Washington, D.C., November 4-7, 1970.

J. Librizzi and R.J. Cresci, "Slingshot - Experimental and Analytic Performance", presented at the 34th Semiannual Meeting of the Supersonic Tunnel Association, held in Atlanta, Georgia, October 8-9, 1970.

S. Lederman, "The Electron Precursor and Application of Raman Scattering", presented at the ARPA Reentry Atomic and Molecular Physics

Meeting, held at the Institute for Defense Analyses, Arlington, Va., October 5-6, 1970.

K. Chung, "Plasma Heating Using Cyclotron Resonances"*, presented at the Seoul International Conference on Electrical and Electronics Engineering, September 1970.

G. Moretti, "Initial Conditions and Imbedded Shocks in the Numerical Analysis of Transonic Flows"+, presented at the 2nd International Conference on Numerical Methods in Fluid Dynamics, held in Berkeley, California, September 16-19, 1970.

C. P.I.B. Reports, Dissertations, and Monographs

S. Lederman and R. Bushman, "Flush Electrostatic Probe in a Continuum Regime". PIBAL Report No. 70-54, Dept. of Aerospace Engineering and Applied Mechanics, December 1970.

T. Koga, "Difficulty and Possibility of Kinetic Theory of Quantum-Mechanical Systems. Part VI - Summary, Addenda and Conclusion"†, PIBAL Report No. 70-41, Dept. of Aerospace Engineering and Applied Mechanics, September 1970.

M.H. Bloom, Coordinator, "Research of Aerophysics Institute for STRATEGIC TECHNOLOGY". Semi-Annual Technical Summary for the period ending 31 August 1970, PIBAL Report No. 70-31.

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†Research supported in part under Contract Nonr 839(38).

IV. ARPA RELATED ACTIVITIES, LECTURES, AND CONSULTANTS

A. ARPA-Related Activities

Dean Martin H. Bloom is a member of the Atomic and Molecular Physics Panel of the Institute for Defense Analyses (IDA); Associate Editor of the Journal of Ballistic Missile Defense Research, published by IDA for ARPA; and is a consulting member of the Plume Technology Working Group, Joint Army-Navy-Air Force.

Professor Robert J. Cresci is a member of the AIAA Ground Test and Simulation Technical Committee of AIAA.

Participation at meetings relevant to the program:

M.H. Bloom and R.J. Cresci attended the ARPA Reentry Atomic and Molecular Physics Meeting, held at the Institute for Defense Analyses, Arlington, Va. on October 5-6, 1970. Prof. S. Lederman also presented a paper at this meeting (previously listed in Section III-B).

E. Levi attend an IDA-ARPA Meeting held in Washington, D. C. on October 7, 1970.

R.G.E. Hutter was present at the Electron Devices Conference held in Washington, D.C. on October 30, 1970.

E. Levi participated in the Project SECEDE Theoretical Panel Review Meeting held in Washington, D.C. on November 18, 1970.

M.H. Bloom was Chairman of a meeting on the Physics of Plumes, which was held at the Aerospace Corporation, El Segundo, California; he also chaired the working group on Aerodynamics at this meeting. R.J. Cresci and S.G. Rubin also participated in the workshop.

B. Lectures

M.H. Bloom gave an invited lecture on "Some Problems in Viscous Flow" at West Virginia University on October 29, 1970.

G. Moretti gave a seminar on "Numerical Treatment of Transonic Flows" at the University of Illinois, Urbana, Illinois, on January 8, 1971.

Lectures at P.I.B.:

September 1970

Professor P. William University College, London	Numerical Methods for Free Interaction Problems
Dr. T. Goodman Oceanics, Inc.	Some Aerodynamic Problems Associated with Traveling in a Tube

October 1970

Dr. A.N. Vystavkin Laboratory Head Institute of Radio Engineering and Electronics Moscow, USSR	Millimeter and Submillimeter Wave at the Institute of Radio Engineering and Electronics, Moscow, USSR
Professor R. Goulard Purdue University	Parameters and Search Methods in Optimum Aircraft Design

November 1970

Professor A. Ferri New York University	Practical Aspects of Sonic Boom Problems

December 1970

Mr. L.R. Lewis Polytechnic Institute of Brooklyn	Phased Arrays with Protruding Elements
Dr. I.E. Vas Princeton University	An Experimental Study of the Flow About a Slender Cone at Hypersonic Speeds

January 1971

Dr. Boris Redkin Machine Building Institute Zaporozhje, Ukraine, USSR	Electromagnetic Wave Scattering by Trees

February 1971

Mr. A. Gessow National Aeronautics and Space Administration	NASA's Role in Developing V STOL Short-Haul Technology
Professor T. Tamir Polytechnic Institute of Brooklyn	Lateral Displacement of Optical Beams Reflected from Leaky Wave Structures
Professor L.B. Felsen Polytechnic Institute of Brooklyn	Ray Methods in Wave Propagation (2 lectures)

C. Consultants

Dr. Nathan Marcuvitz, Professor of Applied Physics, New York University.

V. PERSONNEL ASSOCIATED WITH THE RESEARCH PROGRAM

M. H. Bloom	Principal Investigator Director of Gas Dynamics Research Dean of Engineering
J. Avidor	Research Associate
R. Bushman	Research Assistant
K. Chung	Associate Professor
R. J. Cresci	Professor
E. F. Dawson	Research Assistant
R. Eichler	Graduate Assistant, Senior Grade
H. Farber	Associate Professor
K. Huang	Graduate Assistant, Senior Grade
R.G.E. Hutter	Professor

E. Kawecki	Research Assistant
E. Levi	Professor
S. Lederman	Associate Professor
R. Mons	Research Associate
G. Moretti	Professor
C. Nardo	Postdoctoral Fellow
P.M. Sforza	Associate Professor
R. Valentine	Research Assistant